PC-BASED ELECTRONIC COMBAT SIMULATORS

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ABSTRACT

Recent advances in personal computers (PCs) have made PCs a potentially attractive platform for electronic combat (EC) simulators. Low cost, widespread availability, and a familiar user interface appeal to the user community. Increased performance, a large selection of systems and components, and broadly used development tools and environments attract the developer.

In spite of the many advantages of commercial PCs, their fixed size and architecture impose design constraints. Ideally, an off-the-shelf PC would contain the processing bandwidth, memory, auxiliary storage, and video and audio capabilities to fully simulate an EC environment and a student's equipment suite while providing computer-aided instruction. Users, who define requirements, and designers, who consider design alternatives, need to be aware of the impact various alternatives have on PC resources.

This paper summarizes the essential characteristics of an EC simulator, analyzes software signal generation approaches that drive computational resources, reviews current PC capabilities to support those approaches, and assesses the PC's suitability as a platform for EC simulators and recommends training situations where it should be considered.

About the Author

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INTRODUCTION

The dramatic performance growth in Personal Computers (PCs) has opened new applications for PCs that once were relegated to mid-size computers. Nowhere is this more evident than in the area of audio and video processing. The multimedia PC with its large discs, graphics accelerators and sound boards is one of the fastest growing segments in the PC market. It is these developing capabilities that appear to make the PC an attractive computational platform candidate for an electronic combat (EC) simulator.

The purpose of this paper is to investigate PC suitability as a computational host for EC simulation. The paper summarizes the basic characteristics of EC simulators, analyzes approaches to meeting the fundamental requirements of signal generation and presentation, reviews the state of PC capabilities today, and assesses the PC's suitability. As a means of quantifying capability, an estimate of signal density utilizing various signal generation/presentation approaches is provided. It is hoped that this paper will be helpful to the user defining the requirements of low cost EC simulators and to the designer considering low cost approaches for the simulator.

BACKGROUND

The term PC has two meanings. The narrower meaning is that PC refers to an IBM or "IBM compatible" computer that is based on the Intel 80x86 family of chips of which the Pentium is the latest unit. These PCs currently represent about 80 percent of the personal computer market. A broader meaning of PC is any small desktop or portable computer that is based on one of several other families of chips. The most common systems in this broader group, in addition to the Intel units, include units based on the Motorola 68000 series CPUs or the Apple/IBM/Motorola Consortium's PowerPC. All of these units should be considered for any PC-based trainer. The descriptive PC information presented in this paper is based on the Pentium.

The reasons for PC popularity as a training platform are evident.

Cost. Pentium-based desktop units with 16 MBytes of memory, hard disc sizes exceeding a Gigabyte, 16-bit sound cards, 64-bit graphic accelerators, CDROM, and 17-inch color monitors are available for under $4000.

Performance. At this writing 120-MHz Pentium units rated at 140 SPECint92 and 103 SPECfp92 are available and 132- and 150-MHz units are around the corner. The next generation in the Intel family, the P6, is expected by the end of the year. PC components, such as sound boards and graphic accelerators, are improving in performance at nearly the same rate.

Standardization. The PC's graphical user interface is nearly universal and has enabled a wide user audience to become proficient in using a computer. Standardized open hardware and software interfaces have created a large base of developers that provide an increasing number of new development tools and application software.

Availability. The Intel-based PC family is the most widely distributed system ever and is accessible to the office and home user alike.

ELECTRONIC COMBAT SIMULATOR CHARACTERISTICS

Before looking further into the characteristics of a PC, let us look at what we mean by an electronic combat (EC) simulator. An EC simulator is a training device that presents electromagnetic signals to a student through the use and operation of simulated EC equipment. An EC simulator may provide training in one or more of four broad areas as described in Table 1.

Table 1. Training Areas

Area	Description
EC Principles	Covers basics of transmitting and receiving electromagnetic signals and the nature of the signals themselves. Concept of wide open and tunable receivers. Concept of received signal attenuation due to transmitting and receiving antenna characteristics and motion, range, and environmental effects. Concept of radar systems generating one or more signals in one or more modes. Interpretation of different display devices and formats.
Signal Recognition	Measures signal parameters such as radio frequency, pulse width, pulse repetition interval/pulse repetition frequency (PRI/PRF), scan/illumination patterns, modulation types, etc. Uses signal parameters and audio signatures to identify signals, radar systems, and radar system modes.
Equipment Operation	Develops operational skills using EC equipment including receivers, jammers, radars, and expendable dispensers. May include radio frequency, infrared and optical portions of the electromagnetic spectrum. May also include communication and navigation equipment.
Tactical Environment	Develops situational awareness of the external EC environment and takes appropriate tactical actions including jamming, maneuvering, expendable deployment, and communication calls. Includes interaction with fixed and moving threats and their countermeasures. Includes friendly and hostile entities and their communication and control networks. May include geographic and atmospheric environments.

Ideally, to minimize cost, a PC-based EC simulator should be wholly self-contained within a multimedia PC configuration -- case, monitor, keyboard, mouse, and speaker or earphones. In this configuration, simulated equipment panels and displays are presented graphically on the monitor, controls are activated with a mouse or keyboard, and signal audio is generated by the PC's sound system.

The basic functions performed by an EC simulator are described in Table 2. The fundamental functions, and primary user of computational resources, are the signal generation, receiver simulation, and display generation functions. As will be seen, the approach used to accomplish these functions has a major impact on simulator fidelity and computational resources.

SIGNAL GENERATION AND PRESENTATION

The primary technical challenge in EC simulators is to generate and display realistic audio and video signal representations for the student. In a narrow sense this means rendering a signal that accurately reflects its parametric characteristics, such as frequency, PRI, pulse width, scan pattern, and so on. The audio and video characteristics, of course, have to be correlated with each other, both within single displays and among multiple displays showing the same signal. In a broader sense, the realism of signal representation is also affected by simulated receivers, display devices, and transmitters, as well as simulated environmental and tactical effects.

There are several dimensions to signal presentations that have a major impact on computational resources. These include signal dynamics, signal presentation method, and signal multiplicity. Each of these characteristics in turn have several facets that further affect the use of resources. These concepts are discussed below.

SIGNAL DYNAMICS

"Signal dynamics" addresses how the changing characteristics of a signal are presented to the student. Signal presentation is dynamic for several reasons.

Table 2. EC Simulator Functions

System/Subsystem	Description	Primary/Typical Functions
System	Provides simulator unique system functions	Executive (synchronous processing) Asynchronous event processing Input/output Mode control Scenario control
Environment Control	Maintains the EC environment as seen by the student	Ownship waypoint and maneuvering logic Threat simulation Signal generation Environment effects (occulting, atmosphere, etc) Platform/weapon simulation
Equipment Modeling	Models the operational characteristics of the simulated equipment; may include malfunction modeling	Receivers, display units, jammers, expendable dispensers, comm equipment, navigation equipment
Graphics Modeling	Generates and updates simulator displays showing equipment panels with control, indicators, and displays	Control modeling (switches, buttons, sliders, etc) Indicator modeling (lights, dials, LEDs, etc) Displays (CRT based, showing text or waveform data)
Instructional	Computer-aided instructional features for student; monitor and computer-managed instruction features for instructor	Briefing/dialog windows, dialog response evaluation, equipment operation evaluation, log keeping evaluation, score keeping, trend analysis, etc

Signals are transmitted using techniques that generally vary frequency, pulse width, or PRI. The fact that signal characteristics exhibit frequency agility, chirp, pulse doublets or triplets, stagger, or jitter is often a key in identifying the signal. Various frequency agility schemes are important counter-countermeasures used in EC systems. Antenna and scan patterns profoundly affect signal dynamics and are vitally important in determining the type of system emitting the signal and the system's operating mode, hence its tactical activity. Signal changes occur as a threat reacts to its environment. Typically, a threat that has a capability to transition through search, acquisition and lock-on modes, changes its scan pattern, pulse width, and PRI as it transitions. Other geometric and environmental effects such as transmitter/receiver range, bearing, antenna patterns, and atmospheric conditions cause effects that show up on the student's displays.

A second source of signal dynamism is the effect that receiver systems have on signal presentations. Receiver bandwidth, gain, tuning techniques, antenna patterns, and antenna scan patterns all have an effect on the signal the student sees or hears.

A third source of change is the effect that the display devices have on the signal. Display device controls such as time base or sensitivity on a pulse analyzer greatly affect the form of the signal seen by the student.

The degree to which these sources of change are limited or simulated has a large effect on the computer resources needed for simulation. In fact, the degree to which these sources are accommodated suggests a basic classification of simulator capability and therefore require computational resources. The most basic class, Class I, is that in which all signal characteristics and scheduling are predefined as part of the training scenario. A scheduling cue may be as simple as a time tag. For instance, 30 seconds into a scenario a signal is displayed at a fixed frequency, pulse width, and PRI for a fixed period of time. Certain repetitive characteristics, such as signal amplitude due to antenna scan patterns, are implemented to give a moderate level of dynamism. The transition of a threat through a mode change is simulated by displaying a signal with the characteristics found in the first mode, followed by replacing that signal with characteristics found in the second mode.

Cues other than time may be used. Responding to questions asked in a computer-based training (CBT) scenario may cause one signal to be replaced by another. Likewise, sensing that a student activated a simulated equipment control, such as an oscilloscope time base, could cause one predefined signal to be replaced by another. A shortcoming of this approach, however, is that transitional effects are clumsy to handle at best. For example, cueing on the movement of a receiver tuning control would result in a jerky, unrealistic signal amplitude presentation.

The computational resources required to support a Class I trainer are relatively low. Predefined signal data sufficient to render a visual and audio presentation are accessed from the disc upon a cue and processed. The amount of processing necessary to generate a graphic and audio representation depends on the signal presentation methodology, which will be discussed later.

A Class II simulator accommodates changes in signal presentations caused by actions the student has taken. In a Class II trainer, the signals cannot be fully predefined because it is not known what actions the student may take. If the actions the student can take and the number and combinations of signals that the student interacts with is severely limited, a Class I approach may be possible. Assuming, however, that the student has a reasonably extensive set of options in a moderately dense signal environment, another approach is required. With a simple simulated tunable receiver and an oscilloscope, the student can tune to a signal, select various band passes, and display the signal on a oscilloscope. As the signal enters the band pass the signal increases in amplitude as a function of band pass rolloff; presentation on the oscilloscope changes as a function of trigger sensitivity and provides anywhere from a full-scale view of a pulse to a view of a series of pulses depending on the time scale chosen. Other student actions that might cause changes in the signal representations include moving a steerable antenna, selecting different antennas, or maneuvering the simulated platform.

The processing load of a Class II trainer is much higher than a Class I. The Class II has to at least modify the predefined signal data or, in the more general case, generate a signal representation in real time to accommodate receiver or display device control changes. Again, the specific amount of processing depends on presentation methodology and signal multiplicity.

Class III involves changes to the EC environment due to actions taken by the student. Typical in this class of trainer is the simulation of threat reactions to student actions. In these scenarios generated signals are not the result of predetermined cues. A threat may have acquired the student's platform, but because the student applied jamming, the threat dropped back to a search mode. In this scenario the threat reacts to the fact that it had been successfully jammed. Since the student's actions cannot be predicted, we do not know when the threat will change mode and therefore cannot predict which signals will be transmitted. In addition to jamming, the student may also deploy expendables (flares, chaff, or decoys) or perform maneuvers which may also cause threats to change modes as well as signal presentations.

Class III characteristics add additional processing. The logic for presenting new signals is no longer based on simple cueing but on some level of tactical simulation.

Signal Presentation - Video

The display and audio methods used on the simulated equipment have a major impact on computational resources. At least four different video display methods are used. We will refer to them as indicator, symbolic, synthetic, and direct analog. The indicator method is the simplest and requires the minimum resources to simulate. An indicator may be as simple as a light that flashes when a signal of interest is received. Multiple lights or light panels arranged in various geometric patterns may light or blink to show signal class, perceived lethality, or approximate direction and range of the threat from the student's platform. The computational and graphics load is largely a function of the number of indicators, and their size and blink rates.

The symbolic method uses either alphanumeric characters or special symbols to indicate the reception and classification of signals. Operational equipment using symbolic displays are often complex computer-controlled processors that in themselves may add complexity to the simulation problem. The symbols may be placed on a number of different display formats such as azimuth displays, frequency displays, or simply text lists. The processor and graphics load is largely a function of geometric placement of the symbols on the display and managing the graphical draw, erase, and redraw activity as the signal characteristics change.

Synthetic displays are graphics processor-generated displays that are often simplified digital representations of direct analog displays. Synthetic displays are used by both operational equipment simulators to present the more complex analog signals. An example of a synthetic EC equipment display is a rotating antenna direction finder (DF) display that draws a single vector in a polar display to show the direction of arrival of a signal. Some frequency scan displays are also synthetic where again a single vector shows the frequency of the signal and the vector length of the signal amplitude. Digital storage oscilloscopes use synthetic techniques but the signal rendition can be nearly as complex as a direct analog rendition. The advantages of synthetic signal presentations over their analog counterparts are at least the following. First, the graphics structure of the synthetic signal is usually much simpler, using fewer vectors than its analog version. In the synthetic DF display a single vector is drawn to show direction of arrival, whereas in the analog version the number of vectors drawn is a function of the signal's PRI, the gain of the receiver system and the rotation speed of the DF antenna. Second, synthetic signals are drawn in a noise free environment; the signals and base lines are represented by crisp straight vectors.

The graphics load of synthetic signals can be fairly low depending on the specific equipments simulated and the degree to which "synthetic" freedom is taken. Like the symbolic method the multiplicity of signals is a factor. The size of the simulated display can become a concern. In general, a larger display size means larger signal representations, which in turn means more or longer vectors to draw and erase in generating the signals.

The last method is the direct analog display, in which analog CRT displays are simulated. In the operational equipment, detected video signals are displayed with minimum conditioning. The displays may be polar in the case of DF displays or x/y displays in the case of frequency-based scan displays, frequency-based spectrum analyzers, or time-based pulse analyzers. Operational equipment of this type represents less processor-oriented equipment and is often used to teach fundamental EC principles. Because of direct operator control and increased equipment sensitivity and the fact that the video is a direct analog of the signal, this type of equipment is often used in signal collection and analysis work. The direct analog video shows the detailed transmitted characteristics, environmental effects, receiver effects, and display device effects.

The computational and display requirements of this approach can be extremely high. Developing realistic pulse shapes for a wide range of signal types, receiver detectors, band passes, sensitivity levels, and time bases is a complex process. As signal processing moves from a Class I to a Class II or III, the processing is moved to real-time calculations. The decision to include a simulated effect needs to be carefully balanced against its computational requirements in this approach.

Signal Presentation - Audio

The audio presentation of signals has nearly as many approaches as video presentations and can be as complex. We will look at three methods: tone, synthetic and analog. The tone method is similar to the video indicator approach. When a signal is received, a tone unrelated to the parametrics of the received signal is generated. The most common use of this approach is the warning tone used on several radar and missile warning receivers. The tone may consist of a single frequency that is played for a fixed duration or until acknowledged by the operator. More complex tones, consisting of alternating frequencies to produce a warbling effect, may be used to provide warnings at different urgency levels. The processing to produce tones is quite low and can be simply a matter of selecting predefined tones and turning them on and off at appropriate times.

Synthetic signal audio produces key characteristics of signal audio but is not a direct analog. The basic PRF of a signal is reproduced and perhaps attenuated due to scan and antenna patterns. This often allows the student to identify the class of signal but is usually not sufficient to make identification in many cases. The key advantage of synthetic tones is that rather short samples or definitions of signal segments can be repeated to produce longer durations of signals.

The introduction of signal audio brings into play the problem of synchronizing signal audio with its video rendition. A classic synchronization problem is signal amplitude change due to a scanning antenna. If a video and an audio representation is presented simultaneously, the audio sound level has to be synchronized with the video amplitude. This generally means that they have to be generated from the same data source.

Synthetic audio computational resources depend heavily on the class of signal environment, multiplicity of signals, and the need to correlate to visual presentations. A Class I signal environment with low multiplicity and no audio/visual correlation requires low to moderate processing.

Direct analog audio is similar to direct analog video. In this case a detected signal is passed through an audio amplifier. The accurate audio generation is often more critical than video. Small shifts in PRF, perhaps missed in video, can be heard as tone shifts. Likewise, pulse widths affect the intensity of the sound, and pulse patterns that contain stagger, jitter, doublets, and a multitude of other characteristics have distinctive sounds that enable the trained operator to discriminate and identify signals largely by the way they sound. Transmitting and receiving antenna patterns and certainly antenna scan patterns also have a major impact on the sound and impart identification and tactical information to the student.

To produce audio, the sound has to be either prerecorded and played back or generated. Recorded sound may be used in a limited fashion in a Class I trainer but probably is not useable in the general Class II or III training environments. Generated sound usually requires a detailed description of pulse width and pulse interval components of the pulse pattern, plus additional descriptions of antenna and scan effects. In the instance where the pattern appears not to repeat over a long period of time or has random aspects, the pattern definition can be long and complex.

The processing of these patterns places a very high computational load on the trainer and usually requires the services of digital signal processors (DSPs).

Multiplicity

Multiplicity deals with the number of simultaneous signal elements that have to be dealt with. In EC trainers, two key elements are signals and radar systems. Signals are of prime importance because they are the elements that are presented to the student. Radar systems, or threats, are important because in a Class III signal environment they are the controlling element that determines which signals are active. The concept of threats also allows certain reduction in the computational load if it can be assumed that all signals generated by a threat emanate from a single threat location. That is, range, bearing, occulting, and other environmental effects can be calculated on a threat basis rather than a signal basis. Experience has shown that an average ratio of signals to threats is approximately 2.5 to 1, so the number of some calculations can be more than halved.

Multiplicity has an effect on computational load in three domains: scenario, instantaneous scenario signal generation, and receiver pass band. Scenario multiplicity refers to the total number of signals that the student will see in Class I and II environments and could see in Class III environments. This represents the total number of signal definitions that have to be accessible to the real-time system during the execution of a training scenario. In mission trainers hundreds of signals could be required, resulting in tens of MBytes of data to be stored and eventually read during real time. Algorithms have to be developed to select which signals are to be active at a given instance, and efficient means have to be developed to move data from mass storage to the video and audio adapters. Typically, the sizing and selection is done on a threat basis rather than on a signal basis in the scenario domain.

Another domain of multiplicity is the instantaneous scenario limits. This is the maximum number of signals that are active in the simulated EC environment at any one instant. An upper limit for this number is usually specified for a trainer. The actual instantaneous value is a function of the number of active threats, complexity of the threats, the mode the threats are in, and their visibility to the student's receivers. The number of instantaneous signals affect the number of signals seen on wide open or scanning receiver displays. Often equipment of this type does not provide audio renditions of the signals, so the impact is generally on the visual presentations. Since the broadband, frequency-based displays do not show a lot of signal content, displays of this type can often be implemented using the synthetic approach.

The third domain of multiplicity is the number of signals in the pass band of a tunable receiver. In a dense signal environment it is probable that multiple signals will be in the pass band at once, and the student will have to use various techniques to maximize the amplitude of the signal of interest and minimize the others. The net result is that more than one signal will appear on pulse analyzer displays, DF displays and so on. This effect generally eliminates the Class I signal environment approach because the student needs to work the equipment to isolate the signal of interest as nearly as possible. A common feature of tunable receivers is that they have an audio channel, and the student can listen to the signals as he tries to isolate the one of interest. In the real world there is no limit to the number of signals that can be in the pass band at once; however, from a practical training value standpoint a very small number, on the order of two to four, is usually sufficient. Two gives the student practice in separating signals; more than three or four can make the separating task so difficult that the training value is questionable except in very advanced applications.

The number of signals in the pass band has a large impact on computational resources. Limiting the pass band to one signal makes the Class I approach viable in many training instances. Implementing a Class II environment allows the possibility of multiple signals in the pass band and forces more complex processing to generate visual and audio renditions for multiple independent signals.

PC CAPABILITIES

Now let us look at the capability of PCs to provide the computational resources required by EC simulators. Table 3 provides performance data on Pentium-based PCs being delivered in May 1995 and expected performance data through late 1995 and early 1996. The data show that PCs are indeed powerful performers and will become even more so. The following paragraphs discuss key aspects of PCs and how they relate to EC simulators.

Processor Power. The basic ability of the CPU to execute instructions quickly to process data in pseudo real time is a basic parameter. The computer speed has to be sufficient to realistically model simulated equipment responses to student actions and to realistically model the EC environment with its signals. Table 4 compares the PC with other processors used in training systems.

Memory. With a 4 GByte memory space and numerous models shipping with the ability to put 196 MByte of random access memory (RAM) on the motherboard, memory should not be a limiting factor in using PCs for EC trainers. Peripherals such as graphics processors and sound boards contain their own memory.

Graphics. Graphics accelerators provide an efficient link from the PC local bus to a frame buffer and then to the monitor. The frame buffer stores red, green, blue (RGB) color values for each pixel on the monitor. Scanning logic and high speed digital-to-analog converters generate the RGB signals that drive the monitor at appropriate horizontal and vertical scan rates. Generally, PC-based graphic accelerators only provide simple drawing capabilities, lines and rectangles, and the ability to copy parts of the frame buffer from one place to another. It is up to the host, the PC, to provide the commands to do the draws and moves. This can put a tremendous load on the PC and has a significant impact on the ability of the PC to perform the tasks of an EC computational platform.

Audio. PC sound cards have the ability to produce high quality audio in multiple voices. Most PC sound cards are optimized to play read only memory (ROM) resident sound patches using the Musical Instrument Digital Interface (MIDI) protocol and to record and play back sounds. A number of cards have DSPs on board and provide some level of programmability. The sound cards have the capability to produce highly realistic signal audio; however, the key question is how much PC processing is required to manage or generate the data streams to produce the sounds. The problem is similar to the video issue.

Bandwidth. The ability of the PC to move data between RAM memory, video memory, sound board

Table 3. Characteristics of Pentium-Based PCs

Parameter	Currently Available	Future Activity
Power	120 MHz Pentium processors running at: 140 SPECint92 and 103 SPECfp92	132 and 150 MHz Pentium processors expected Q3. P6 processor at 132 MHz, 200 SPECint92, expected by end of 1995
Memory	4 GByte memory space Most vendors offer 128 MByte installable, some offer up to 512 MByte	
Graphics	Typical offerings: 1600 x 1200 res 65,000 colors 75 Hz vert Res 4 MByte VRAM PCI bus interface	Windows 95 expected to support OpenGL. Will probably be too slow for simulation.
Audio	Typical offerings: 16-bit resolution 44.1 kHz sample rate 32 simultaneous sounds Record/play back MIDI interface 2 MB ROM for sound samples	P6 expected to have DSPs on system board, which will probably handle audio
Bandwidth	PCI local bus transfer rate at 132 Mbyte/ sec	
Mass Memory	Hard Discs (3.5") 9.5 GByte 13.3 - 40 MB/sec 15.1 msec access CD-ROM (6X) 680 MB/disc 900 KB/sec 145 Msec access	
Mass Memory Adapters	Enhanced IDE Max 8.4 GByte 13.3 MByte/sec DMA or 11.1 in PIO SCSI-2 Fast 10 MByte/sec SCSI-2 Wide 20 MByte/sec (16 bit) 40 MByte/sec (32 bit)	Enhanced IDE 137 GB & 16.6 MB/sec by year end Ultra-SCSI 20 MByte/sec (8 bit wide) 40 MByte/sec (16 bit wide) SCSI-3 (Serial) 100 MByte/sec bursts
Interconnectivity	Ethernet Optical Some multi CPU boards available	P6 to support quad processors

Table 4. CPU Performance Comparisons

Manufacturer	Model	Format	Clock Rate (MHz)	Benchmark (SPECInt92/SPECfp92)
DEC	Alpha	64 Bit	275	190/290
Intel	88110	16 Bit	50	51/73
Intel	Pentium	32 Bit	100	92/81
Intel	Pentium	32 Bit	120	140/103
Mips Technologies	R4400	64 Bit	150	97/101
Mips Technologies	R4600	64 Bit	150	104/81
Motorola/Apple/IBM	PowerPC 601	32 Bit	100	105/125
Motorola/Apple/IBM	PowerPC 604	32 Bit	133	200/200
Sun Microsystems	Micro SPARC II	32 Bit	110	76/65
Sun Microsystems	Super SPARC II	32 Bit	90	148/143

memory, and disc storage is largely a function of bus. technology. The Pentium uses a local bus to make these transfers. The fastest local bus at this time is the Peripheral Component Interconnect (PCI) bus with a transfer rate of 132 MB/sec. The adequacy of this bus is largely dependent on the amount of video and audio data that has to be transferred.

Mass Memory. The performance and capacity of hard discs have been increasing steadily. The PC standard 3.5-inch hard disc is currently available in sizes up to 9.2 GBytes. Disc adapters are commonly available in Enhanced IDE and SCSI formats. Transfer rates, depending on the format, range from 10 to 40 MByte/sec, and access times under 10 msec are not uncommon. Improved performance is expected in both formats over the next year. The adequacy of mass memory capability of PCs appears to be sufficient for EC trainers.

Interconnectivity. EC trainers are often connected together to support combined training and/or connected to instructor stations to allow an instructor to monitor or control the training scenario. PCs support a number of LAN protocols, many of which are more than adequate to interconnect stations. Several vendors support dual Pentiums in a system. While these "multi-processors" would undoubtedly improve system performance, they are beyond the scope of this paper.

PC's SUITABILITY AS AN EC SIMULATOR PLATFORM

A review of the current PC capability shows that the primary limitations are in the area of graphics and audio generation. Depending on trainer requirements, these could affect processing power and bandwidth needs. Video and graphics generation are the very capabilities which are required to support the primary function of an EC trainer; therefore, it is in this critical area that tradeoffs between trainer requirements and PC capability will be made.

The key system parameters the designer has to work with are the number and type of EC equipments to be simulated, the class of signal environment to be generated, the audio and video presentation methods provided, and the number of active signals.

The number and type of simulated equipment is important for several reasons. The equipment selected determines the number and type of video displays, the audio requirements, and the complexity of the equipment model. The size of equipment panels also impacts the area needed on the graphic display. In general, a PC-based simulator will be limited to approximately six to eight equipment panels and they will undoubtedly be smaller than actual operational equipment.

The maximum number of active EC displays is probably not more than three or four and then only if the simpler signal environment and presentation methods are used. A greater degree of interaction with the environment or a higher fidelity of signal presentation will reduce the number of active displays and number of simultaneous signals processed.

A system as seemingly simple as a basic EC simulator consisting of a scanning receiver with frequency pan display, a tunable receiver with a pulse analyzer display, and a rotating antenna DF display requires a careful review of system requirements and design tradeoffs. Requirements imposed on the simulator by the training areas described in Table 1 or functions described in Table 2 have to be weighed against their impact on computational resources.

Table 5 provides rough estimates of the signal densities that can currently be expected to be accomplished on a PC-based simulator. The sizing is extrapolated from designs of existing EC trainers or trainers under development. As can be seen from the table a PC is a viable basis for a simulator, but its limitations must be understood.

RECOMMENDATIONS

PCs should be considered as a low cost platform for EC simulators designed to meet limited training needs. In training situations where a very small number of high fidelity signal presentations or a moderate number of lower fidelity signal presentations are required, the PC is a viable candidate. Signal recognition, basic EC principles, and single equipment operation trainers fall into this category.

Where a larger number of signals with at least moderate fidelity and dynamics, interactive environments, or trainer functionality in addition to signal generation, receiver simulation, and display presentation is needed, the PC is not ready yet. Advanced EW principles, equipment suite operation, realistic mission scenarios, or trainers with significant computer aided instruction requirements will require more computational power than can be provided by the standard PC.

Table 5. Estimated Signal Density Capability

Presentation Method	Class I	Class II	Class III
Display			
Indicator	100	100	50
Symbolic	50	20	10
Synthetic (Frequency-based)	50	20	10
Synthetic (Time-based)	1	2	1
Synthetic (Polar-based)	1	2	1
Analog (Frequency-based)	10	5	2
Analog (Time-based)	1	1	1
Analog (Polar-based)	5	1	1
Audio			
Tone	50	50	50
Synthetic	20	10	10
Analog	8	2	2

Where a larger number of signals with at least moderate fidelity and dynamics, interactive environments, or trainer functionality in addition to signal generation, receiver simulation, and display presentation is needed, the PC is not ready yet. Advanced EW principles, equipment suite operation, realistic mission scenarios, or trainers with significant computer-aided instruction requirements will require more computational power than can be provided by the standard PC.

The development of PCs should be carefully monitored. The PC environment is extremely dynamic with more vendors getting into the market place. Their capabilities will continue to increase. Increased power and capabilities of the CPUs, video accelerators, and sound cards; the addition of DSPs to the motherboard; the availability of multi-CPU and multi-monitor systems all alter the equation that determines the point that PCs become a viable, if not the preferred platform, for EC simulators.

SUMMARY

The PC-based EC trainer unquestionably has a place in training inventory. The PC's low cost and wide availability make it an attractive candidate as an EC trainer computational platform. The PC, as currently available, does have graphics and audio generation limitations that limit the capability of the trainer in the signal generation, receiver simulation, and display capability. These current limitations can be mitigated by limiting signal dynamics capability, display presentation methods, and signal density. The PC market is extremely dynamic; every indication is that the performance growth over the next several years will continue at the same rate as the last several years. In particular, the current focus on multimedia technology should ensure the continued development in the critical audio and video components.